



INFRARED RADIATION CALCULATOR

Example Problem Guide

To save time in the handling of calculations of radiant energy, the Sensors IR Radiation Calculator presents energy data in various units as derived from a source temperature that can be set on the rule in any one of four temperature scales. The basic functions and formula upon which the Calculator is based are presented on the faces. To best illustrate use of the Calculator several sample problems are given below followed by a partial bibliography of sources of additional information on radiation calculations. Practical values of emissivity for industrial materials are shown also.

Example 1

The graphite plate of a particular metal-shell vacuum-tube operates at 500°C . At an emissivity of only about 0.08 (Handbook of Chemistry and Physics), it is only eight per cent as good an energy radiator as a blackbody. If 500°C is set at the index, it is found that a blackbody radiates 2 Watts per square centimeter while carbon, at its low value of emissivity, radiates 1.6×10^{-1} Watts per square centimeter as read opposite the appropriate emissivity. This radiant power is absorbed in the metal envelope of the tube. Assuming a temperature of 100°C at the metal, we may compute the energy radiated to the carbon by the metal. In this case, since the metal is the surrounding, the emissivity factor of the metal does not enter into the calculation. With 100°C set at the index the power reading at the index is 1.1×10^{-1} Watts per square centimeter. By subtraction it is found that 5.0×10^{-2} Watts per square centimeter is the net radiation retained at the metal envelope from plate dissipation.

If a glass envelope is used, the problem becomes more complex, since a portion of the radiation is transmitted by the glass. It is then desirable to find how much of the radiated energy is transmitted. At 2.5 micrometers this glass begins to be a poor transmitter of infrared radiation. On the percentage-increment scale, 2.5 micrometers for this particular temperature (500°C) falls at

6 per cent. Thus approximately 6 per cent of the power is transmitted by the glass, while 94 per cent of the energy radiated by the plate is absorbed by the glass. Since the percentage-increment scale is for blackbody distribution, the percentage of energy transmitted is only an approximation.

Example II

In another device it is desirable to use a lead-sulfide photoconductive detector to measure the radiant power from a blackbody radiator varying between 1000 and 2000°F. To determine the order of accuracy to be expected in such an application, the spectral characteristics of the lead-sulfide cell are important. By an approximation of the published spectral response we assume that the cell does not respond to wavelengths longer than 3.3 micrometers. Then for 1000°F, the percentage increment scale will show that only about 20 percent of the power from the source is available to lead-sulfide cell to be converted into a usable signal. At 1500°F, reading the percentage-increment scale again, 40 per cent of the power is available for signal at the lead-sulfide cell. At 2000°F, 3.3 micrometers falls opposite about 56 percent; thus, 56 percent of the energy of the blackbody at this temperature is available for signal at the lead-sulfide cell. Thus, an increase in signal is expected from PbS when the blackbody temperature varies from 1000°F to 2000°F. This increase is a factor of 24.

Example III

For a filter problem it may be desirable to obtain the source energy that falls in a wavelength increment. Suppose for a blackbody source at 1000K the power falling between 1.0 and 1.2 micrometers is desired. The maximum, of course, falls at 2.89 micrometers as seen on the wavelength scale. The total radiated power is 5.7 Watts per square centimeter. At 1.0 micrometer 0.03 percent of the total energy falls below 1 micrometer and at 1.2 micrometer 0.22 percent falls below 1.2 micrometer. Thus computing the percents of the energy below these wavelengths and subtracting one finds 0.011 Watts per square centimeter between 1.0 and 1.2 wavelength.

Using the $M_\lambda/M_{\lambda \text{ max}}$ (ratio of power at wavelength to power at maximum wavelength) scale for this same problem it is found that 0.042 of the power at the maximum falls at 1.1. The maximum value is 1.28 Watts per square centimeter per wavelength increment.

Example IV

Another problem might be the desirability of plotting blackbody curves at some temperature. For a temperature of 1000K, set this temperature on the index. $M_\lambda/M_{\lambda \text{ max}}$ values are found above the wavelength scale

from which the curve of spectral emittance vs. wavelength can be plotted.

Example V

Instead of determining the power in Watts emitted by a source operating at some temperature it is possible to get the number of photons per second per unit source area. For a source of 1000K set the index again at this temperature and read 1.55×10^{20} photons per second per square centimeter on the proper scale.

The next scale below, gives photon energy in electron Volts for a particular setting of source temperature which corresponds to the wavelength maximum or any wavelength within the range of the calculator. The wavelength is set on the index and the photon energy is read on that scale.

At the temperature of 1000K the wavelength maximum is 2.89 and the photon energy is 0.43 electron Volts. For a wavelength of 0.55 (green light) the photon energy is 2.25 electron Volts.

Also when working with photoemissive surfaces the work function of the material might be expressed in electron Volts, e.g. for some photocathodes the work function is 2.0 electron Volts. Using the calculator this corresponds to radiation of 0.62 (6200Å) wavelength.

Likewise a simple conversion is available to waves per centimeter or wave numbers corresponding to some wavelength.

Example VI

RANGE CALCULATIONS: For a given target it is possible to compute the power for a wide range of distances from the source. Assuming a blackbody target at temperature 2500K, the power radiated by the target is 2.2×10^2 Watts per square centimeter. Using the range portion of the calculator it is found that 7.0×10^{-5} Watts per square centimeter is incident on one square centimeter of surface 1×10^3 centimeters from one square centimeter target area. At a distance of 10 nautical miles the radiation received would be 2.04×10^{-11} Watts per square centimeter.

Example VII

SIGNAL POWER CALCULATION: You have a 10^4 cm² target whose temperature is 600K. Its range is 1000 meters from a sensor with a round collecting apperture of 20 cm radius. Assume no atmospheric effects and that the target emissivity is unity. How much power arrives at the detector in the spectral band from 2.0μ to 5.5μ.

1. Determine the total power M on M scale (0.72 Watts/cm²)
2. Go to $\frac{M_{0-\lambda}}{M_{0-\infty}}$ scale & read 0 to 2μ value (0.24%)
 $M_{0-2\mu} = 0.0024 \times 0.72$ (0.0017 Watts/cm²)

3. Go to $\frac{M_{O-\lambda}}{M_{O-\infty}}$ scale & read 0 - 5.5 μ value (35%)
 $M_{O-5.5\mu} = 0.35 \times 0.72$ (0.25 Watts/cm²)
4. Subtract $M_{O-2\mu}$ from $M_{O-5.5\mu}$ (0.25 Watts)
5. For the range equation read off irradiance, E, at 1 kilometer range (2.5 x 10⁻¹¹)
6. $E = 2.5 \times 10^{-11} \times 10^4$ the target area (2.5 x 10⁻⁷ Watts/cm²)
7. To find E x A_A

$$A = \pi R^2$$

$$A = 3.1416 \times 400 \text{ cm}^2$$

$$A = 1.26 \times 10^3$$

Thus the total power coming into the detector is
 $\Phi = EA = 2.5 \times 10^{-7} \times 1.26 \times 10^3$ (3.15 x 10⁻⁴ Watts)

Bibliography:

- A. H. Canada, "Simplified Calculation of Blackbody Radiation",
 General Electric Review, Dec., 1948.

The Sensors IR Radiation Calculator is printed on stabilized paper-board and is satisfactory for order-of-magnitude calculations.

Additional Calculators and Example Problem Guides may be obtained from Sensors, Inc. at \$5.00 per set, postpaid.

Sensors is a leading supplier of devices and systems for infrared detection and measurement. High performance thermopile IR detectors using the most advanced thin film techniques. Average temperature radiometers with digital readout for non-contact temperature measurement. And a host of other products and systems ranging from security sensors and gas analyzers to special purpose systems for non-destructive tire & weld testing.



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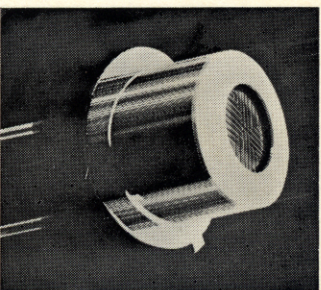
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INFRARED RADIATION CALCULATOR

0-3 BRASS, GOLD

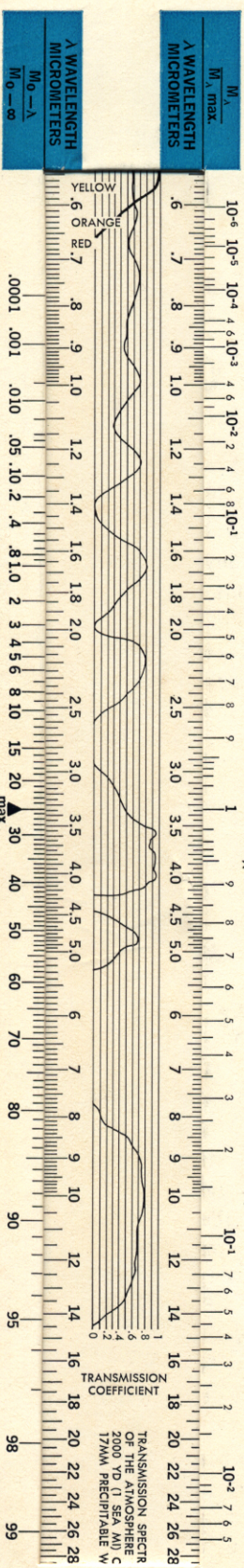


TEMP. (°C) CENTIGRADE	TEMP. (K) KELVIN
0	273
100	373
200	473

°C + 273

EMISSIVITY	WATTS/SQ. CM	WATTS/SQ. CM/MICROMETERS $\Delta\lambda$ AT MAXIMUM	M_{λ} max.
1.0	10	3	ϵ
0.8	8	2	M
0.6	6	1.5	
0.4	4	1	
0.2	2	0.5	
0.1	1	0.25	
0.05	0.5	0.125	
		0.0625	
		0.03125	
		0.015625	
		0.0078125	
		0.00390625	
		0.001953125	
		0.0009765625	
		0.00048828125	
		0.000244140625	
		0.0001220703125	
		0.00006103515625	
		0.000030517578125	
		0.0000152587890625	
		0.00000762939453125	
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		0.000000000000000000108420217248550443400	

RATIO OF EXITANCE AT CORRESPONDING WAVELENGTH TO M_{λ} MAX. FOR A BLACKBODY AT TEMPERATURE (T),



PERCENTAGE INCREMENT OF EXITANCE FALLING BELOW ANY WAVELENGTH FOR A BLACK BODY AT TEMPERATURE (T).

SENSORS INFRARED RADIATION CALCULATOR

PLANCK'S EQUATION :

$$M_\lambda = C_1 \lambda^{-5} (e^{C_2/\lambda T} - 1)^{-1}$$

WIEN'S DISPLACEMENT LAW :

$$\lambda_m = \frac{C}{T}$$

STEFAN-BOLTZMANN LAW :

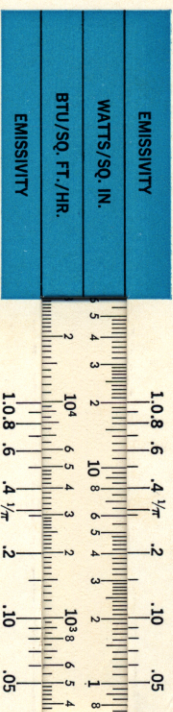
$$M = \epsilon \sigma T^4$$

STEFAN-BOLTZMANN CONSTANT (σ) :

- 5.6697 x 10⁻⁵ ergs cm⁻² K⁻⁴ sec⁻¹
- 5.6697 x 10⁻¹² watts cm⁻² K⁻⁴
- 1.355 x 10⁻¹² cal cm⁻² K⁻⁴ sec⁻¹
- 3.658 x 10⁻¹¹ watts in⁻² K⁻⁴
- 1.798 x 10⁻⁷ Btu ft⁻² K⁻⁴ hr⁻¹
- 5.268 x 10⁻¹² Kwh ft⁻² K⁻⁴ hr⁻¹
- 4.530 x 10⁻⁹ Kcal ft⁻² K⁻⁴ hr⁻¹



WAVES/CM (CM⁻¹)



SYMBOLS AND PHYSICAL CONSTANTS

- M_λ = SPECTRAL RADIANT EXITANCE
Watt-cm⁻² micrometers⁻¹
- M = TOTAL RADIANT EXITANCE
- T = ABSOLUTE TEMPERATURE OF RADIATING BODY (K)
- T_0 = ABSOLUTE TEMPERATURE OF SURROUNDINGS (K)
- λ = WAVELENGTH IN CENTIMETERS OR MICROMETERS
- λ_m = WAVELENGTH IN MICROMETERS OF MAXIMA OF BLACK BODY CURVE
- α = CONSTANT FOR BLACK BODY = 2897.9 μm-K
- $C_1 = 2\pi^5 h^6 / 15 \epsilon_0^3 k^3 = 3.7413 \times 10^{-12}$ watt cm²
- $C_2 = hc/k = 1.4388$ cm-K
- $e = 2.71828$ NAPERIAN BASE
- ϵ = EMISSIVITY FACTOR (BLACK BODY = 1)
- σ = STEFAN-BOLTZMANN CONSTANT
- c = VELOCITY OF LIGHT = 2.99793 x 10¹⁰ cm/sec
= 2.99793 x 10¹⁴ micron/sec
- h = PLANCK'S CONSTANT = 6.6256 x 10⁻³⁴ watt sec²
- k = BOLTZMANN'S CONSTANT = 1.38054 x 10⁻²³ watt sec²/K
- $1/\pi$ = MEAN, NORMALIZED RADIANT FLUX PER UNIT PROJECTED SOLID ANGLE

